ESO 1808

Output Quotas and Strategic Interaction in Processed Food Markets

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Abstract

This paper considers the impact of output quotas on food processors for different specifications of duopoly behavior. For a restriction on one firm, rents are shifted to the other under quantity competition while both benefit under price competition. For quotas on both firms, each benefits whatever the nature of competition.

Introduction

In the past decade, agricultural economists have treated the food and agricultural sectors as being part of a series of vertically interrelated input-output markets known collectively as the 'food chain' (see, Burns *et al*, 1983 and Connor *et al*, 1985). In analyzing this economic system, it is important to recognize the existence of two forms of market interdependence. On the one hand, there is **horizontal** competition within any given sector and, on the other hand, there are important **vertical** links between the sectors. Whilst a good deal of progress has been made in understanding the competitive process within different parts of the food chain, agricultural economics has yet to explore, in any great detail, the ways in which horizontal market interdependencies can interact with vertical market interdependencies. *A priori*, these relationships become critical in analyzing the impact of government policy on the food chain, in particular the effects of agricultural and food policy. Government intervention in either or both of the agricultural and food manufacturing sectors may affect the distribution of economic welfare between them and also consumers.

The aim of this paper is to explore, in a theoretical manner, the effects of strategic interaction in the food industries on the outcomes of government intervention designed to affect the agricultural sector. A distinction can be made between **indirect** and **direct** agricultural policies that affect food manufacturing. The former relate to policies such as agricultural support prices and import tariffs which raise input costs to food processors. The latter relate to policies such as output quotas that are imposed directly on food processors as a means of restricting agricultural output. Such policies have been used in the European Community (EC) sugar processing sector.

The outline of the paper is as follows: in Section 1, a simple model of duopoly is set up in order to characterize equilibria between a firm processing a domestically produced agricultural commodity and a firm processing an imported agricultural commodity. Section 2 considers the effects of direct agricultural policies in the form of output quotas. If a quota is placed on only one of the two food processors, it is shown that such a policy can have quite different effects, depending on the underlying game being played by the two firms. However, when quotas are placed on both firms, they act like capacity constraints such that, following Kreps and Scheinkman (1983), the equilibrium of a game in price will be the same as that in quantities. Finally, in Section 3, the results of this analysis are summarized.

1. Duopoly Equilibrium

In this section, a simple model of duopoly in food processing is set up. It is assumed that the relevant food processing industry comprises two firms who are first-stage food processors. Firm 1 converts a domestically produced agricultural commodity into a storable food product, while firm 2, who may be a foreign firm, converts an imported agricultural commodity. The two types of raw agricultural commodity are not necessarily perfect substitutes and the processed products may be perfect or imperfect substitutes for each other. The equilibrium concept employed is that of Nash equilibrium, each firm setting their relevant strategic variable (quantity or price) in order to maximize profits, given the action of the rival firm. The technology of food processing is assumed to be one of constant returns and the cost structures are similar for both firms. It is also assumed that costs are dominated by purchase of the raw agricultural commodity.

If s_i is the strategic action of firm i, i = 1, 2, and profits are π^i, a set of strategic actions is a Nash equilibrium if, for all i and any feasible action s_i:

(1) $$\pi^i(s_i^*,s_j^*) \geq \pi^i(s_i,s_j^*) \qquad i \neq j$$

i.e. the set of actions is an equilibrium if neither firm can change its action to increase its profits given the action of the other firm. So assuming the firms' profits functions are twice differentiable, the first-order condition for a Nash equilibrium is:

(2) $$\pi_i^i(s_i^*,s_j^*) = 0 \qquad i \neq j$$

where the subscript is the relevant partial derivative of the profits function. The second-order condition is such that, for a strategic action $s_i = s_i^*$, the following holds:

(3) $$\pi_{ii}^i(s_i^*,s_j^*) \leq 0 \qquad i \neq j$$

This will be satisfied if each firm's profit function is strictly concave in its own action[1], consequently (2) will be sufficient for a Nash equilibrium.

Defining $s_i = R_i(s_j)$ as firm i's best action given that firm j chooses s_j, then the first-order condition (2) can be re-defined as:

(4) $$\pi_i^i(R_i(s_j),s_j) = 0 \qquad i \neq j$$

where $R_i(s_j)$ can be thought of firm i's reaction to s_j. Therefore, a Nash equilibrium involving the two food firms is a set of actions (s_1^*,s_2^*), where:

(5) $$s_1^* = R_1(a_2^*) \quad and \quad s_2^* = R_2(a_1^*)$$

In equilibrium, each firm sets its strategic variable optimally given the other firm's anticipated action, i.e. equilibrium is where the reaction functions of the two firms cross.

In the subsequent analysis, the interest is in determining the comparative static effects of introducing output quotas on the food processing sector. This requires analysis of the slope of the reaction functions for different strategic actions by the two firms. The slope of firm i's reaction function is obtained by differentiating expression (4):

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[1] See Friedman (1977) for discussion of the conditions sufficient to generate a stable Nash equilibrium.

(6) $$R_i'(s_j) = \frac{\pi_{ij}^i(R_i(s_j),s_j)}{-\pi_{ii}^i(R_i(s_j),s_j)} \qquad i \neq j$$

Given concavity of π^i, the sign of the slope of the reaction function is determined by the sign of the cross partial derivative of firm i's profits with respect to its rival's action, i.e. π_{ij}^i. The following conditions give the slope of the function:

(7) *If* $\pi_{ij}^i > 0$, *the reaction function is upward sloping*
If $\pi_{ij}^i < 0$, *the reaction function is downward sloping*

Given (7), the nature of the strategic action adopted by the two firms can be considered. If s_i relates to quantity, then each food firm sets output in order to maximize profits, given the anticipated output choice of the other firm. If goods are substitutes, quantity competition is usually represented by downward-sloping reaction functions and the Nash equilibrium corresponds to the familiar Cournot outcome. If s_i relates to price, then each food firm sets price in order to maximize profits, given the anticipated price choice of the other firm. For substitute goods, price competition is normally characterized by upward-sloping reaction functions and the Nash equilibrium is the Bertrand outcome[2].

2. Comparative Statics and Output Quotas

Suppose the government chooses either to impose restrictions on food processors themselves in order to restrict output in the farm sector, or introduces such a policy in the farm sector that, *de facto*, acts as a direct policy on food processors, i.e. where the raw commodity is sufficiently critical in processing that a quota on its output is essentially a quota on the processed good's output.

[2] Following the terminology of Bulow, Geankoplos, and Klemperer (1985), when two goods are normal substitutes, under Cournot, the goods are 'strategic substitutes', and under Bertrand, the goods are 'strategic complements'.

It is assumed that, prior to implementation of the quota, intervention prices and import tariffs are already in place. This means that while farmers face a reduction in output, they are guaranteed the same price per unit of output. Two policy experiments are conducted; first, a quota is placed on the output of the firm processing domestic agricultural output; second, a quota is also placed on the processor importing the raw agricultural commodity. This could be regarded as a stylization of the UK sugar processing industry, where EC sugar beet quotas operate through British Sugar, whilst Tate and Lyle are subject to a quota on their imports of cane sugar. The effects of these policies are considered in situations where firms initially play a game in quantities and prices respectively.

Quota placed on Processing of Domestic Agricultural Commodity

Once quota constraints are introduced into the model, the way firms behave will clearly be affected. Where the strategic variable is quantity, a quota on firm 1 has the following effects;

Proposition 1. Given a game in quantities with downward-sloping reaction functions, implementing a quota on firm 1's output:

(i) *Lowers the output of firm 1 and increases that of firm 2*

(ii) *Increases food prices if the goods are perfect substitutes*

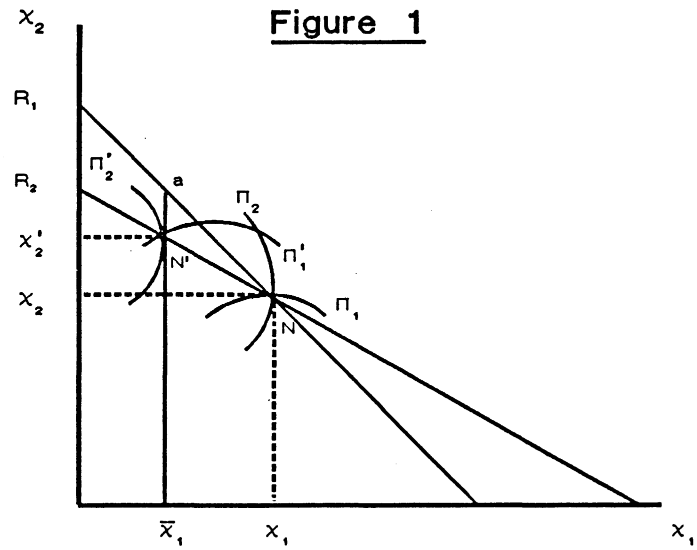
(iii) *Increases the profits of firm 2 at the expense of firm 1*

Proof.

The proof here is represented in **Figure 1**, where R_1 and R_2 are the initial reaction functions of the two firms, and N is the initial equilibrium.

With a quota of $\bar{x}_1$ imposed on the firm processing the domestic agricultural commodity, its reaction function becomes a vertical line at **a**, and below the quota it is R_1. For firm 2, it now knows that a quota has been placed on the other firm, hence it will choose that level of output, given the quota, that will maximize its profits, i.e. where the iso-profit contour π_2' is just tangent to the quota constraint at N′. The rest of the proof is straightforward; output of firm 1 falls from x_1 to $\bar{x}_1$ and that of firm 2 rises from x_2 to x_2'. The price of both goods increases if they are perfect substitutes, otherwise the price effect is ambiguous[3]. Also, the profits of firm 2 increase from π_2 to π_2' and those of firm 2 fall from π_1 to π_1'.

Figure 1



Essentially, this is the result illustrated in Fung (1989), and can be thought of in terms of the quota acting as a credible pre-commitment on the part of firm 1 to decrease its output, hence shifting profits to firm 2 in the form of quota rents. In terms of the effects on consumers, they lose from higher food prices if the goods are perfect substitutes.

When the two firms compete in price, a quota imposed on firm 1 has the following effects;

Proposition 2. When price is the strategic variable and reaction functions are upward-sloping, implementing an output quota on firm 1's output:

(i) Lowers the output of both firms

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[3] In the case of perfect substitutes, the predicted price changes follow from the stability conditions for a Cournot-Nash equilibrium, i.e. the output of firm 1 falls by more than the increase in firm 2's output because R_1 is steeper than R_2. See Dixit (1986) for further discussion.

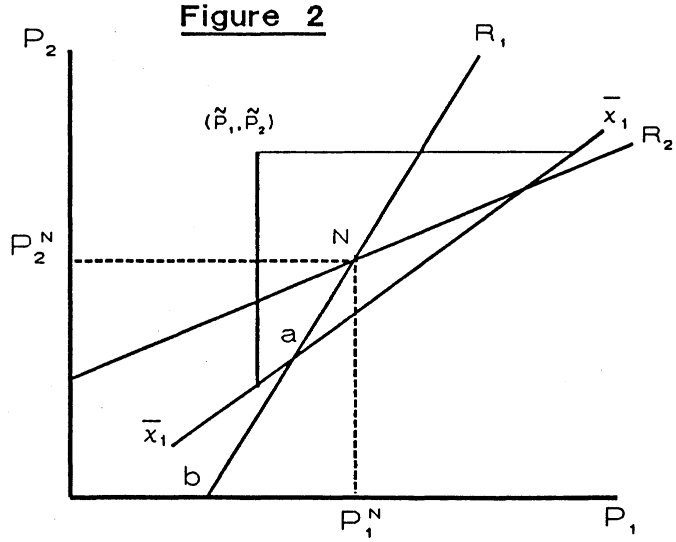
(ii) *Increases the prices of the processed products, although firm 2 will randomize over two prices*

(iii) *The profits of both firms increase*

Proof.

The proof here follows analysis originally suggested by Krishna (1989). Consider **Figure 2,** where R_1 and R_2 represent the usual reaction functions in a price game, N is the initial equilibrium.

Figure 2



Taking a direct demand function, and assuming a quota restraint of $\bar{x}_1$ is placed on firm 1, then the quota will be just binding at prices p_1 and p_2 if:

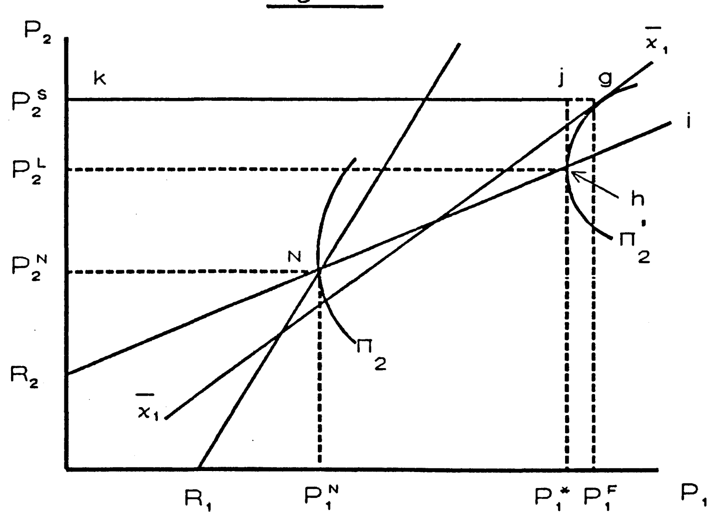
(8) $$\bar{x}_1 = D_1(p_1,p_2)$$

This implicitly defines the price p_1 that will just satisfy the quota given firm 2's price p_2, i.e. $p_1 = f(p_2,\bar{x}_1)$. The set of prices that will satisfy the quota is given by the line $\bar{x}_1\bar{x}_1$ in **Figure 2.** This line lies to the right of the no-quota equilibrium as the quota is assumed to be more restrictive. At points to the left of $\bar{x}_1\bar{x}_1$, firm 1's price is lower than that necessary to satisfy the quota, hence the quota is binding. At points to the right of $\bar{x}_1\bar{x}_1$, the quota is not binding. Hence firm 1's reaction function can be defined as:

$$(9) \quad \begin{array}{l} a\overline{x}_1 - f(p_2,\overline{x}_1),\ if\ f(p_2,\overline{x}_1) \geq RF_1,\ or\ p_2 \geq p_2^N \\ ba - RF_1,\ if\ f(p_2,\overline{x}_1) \leq RF_1,\ or\ p_2 \leq p_2^N \end{array}$$

Suppose, therefore, that firm 2 charges $\tilde{p}_2$ and firm 1 charges $\tilde{p}_1$, demand for firm 1's processed product will exceed the quota. In order to make the quota bind, a rationing rule is required. Following Krishna, it is assumed that costless arbitrage[4] occurs, whereby consumers of firm 1's good who are able to purchase at $\tilde{p}_1$, re-sell at a higher price that clears the market, i.e the price necessary for the constraint to be satisfied. Hence, firm 2 can always make the quota bind by charging a price above the line $\overline{x}_1\overline{x}_1$.

Figure3



Given firm 1's reaction function under the quota, firm 2's is considered in **Figure 3.** Define two price combinations; (p_1^F,p_2^S) where firm 2's iso-profit contour π_2' is just tangent to the quota constraint at **g**, and (p_1^*,p_2^L) where π_2' intersects firm 2's reaction function at **h.** If firm 1 sets a price $p_1 > p_1^*$, then firm 2 does not make the quota bind as it can sell at a price along its reaction function **hi** which generates profits in excess of π_2'. If $p_1 < p_1^*$, firm

[4] Tirole (1989) describes this as "efficient" rationing in that consumer surplus is maximized.

2 will set the price p_2^s in order to make the quota bind. If $p_1 = p_1^*$, firm 2 is indifferent between setting p_2^s and p_2^L.

Consequently, firm 2's reaction function is discontinuous along the lines **hi** and **jk** and never intersects firm 1's reaction function. Therefore, a Nash equilibrium in pure strategies does not exist. As Krishna shows, the mixed strategy equilibrium is one where firm 1 charges p_1^* whilst firm 2 randomizes over the prices p_2^L to p_2^s. In the mixed strategy equilibrium, firm 1's expected profits rise to the level associated with p_1^*, whilst those of firm 2 rise to π_2'. As equilibrium prices are above (p_1^N,p_2^N), the output of both firms is likely to fall. Hence in contrast to a game in quantities, a quota placed on the output of firm 1 results in both firms acting less competitively and both would have an incentive to maintain such a policy. As a result of this policy consumers face higher food prices.

Quota placed on both Food Processors

The case of quota constraints on both firms is also considered. It is assumed that the quota on firm 2 is similar to that placed on firm 1. In the case of a quantity game, this has the following effects;

Proposition 3. When quantity is the strategic variable and reaction functions are downward-sloping, implementing an output quota on both firms 1 and 2:

(i) Lowers the output of both firms

(ii) The prices of both products will rise

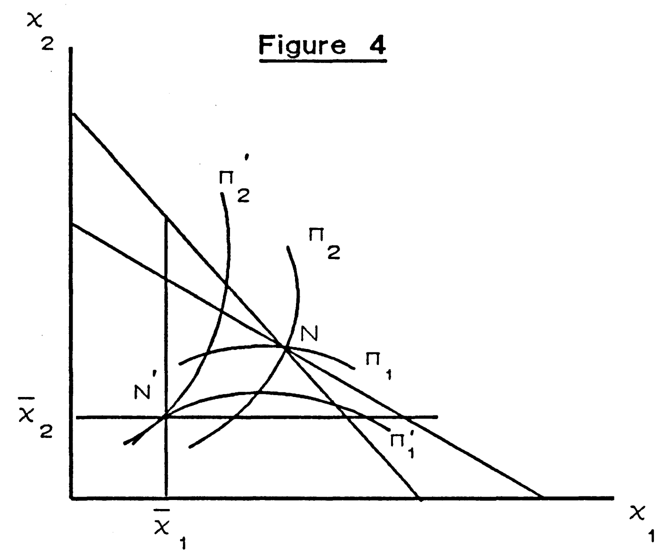
(iii) The profits of both firms increase, assuming input costs remain at the support price level

Proof.

This result is illustrated in **Figure 4**, where the outputs of both firms are restricted to $\bar{x}_1$ and $\bar{x}_2$ respectively, and profits rise to π_1' and π_2'.

Basically the quotas allow the two firms to act more collusively, although the result is dependent on quota symmetry. In terms of welfare, both firms gain by extracting quota rents, the consumer loses from higher food prices and farmers receive the same per unit price for a lower level of output. Consequently, both firms would have an incentive to maintain/increase the level of output quotas.

Figure 4



When output quotas are imposed on both firms in the case of a game in price, the following results hold;

Proposition 4. Given an initial game in price and upward-sloping reaction functions, implementing quotas on firms 1 and 2:

(i) *Lowers the output of both firms*

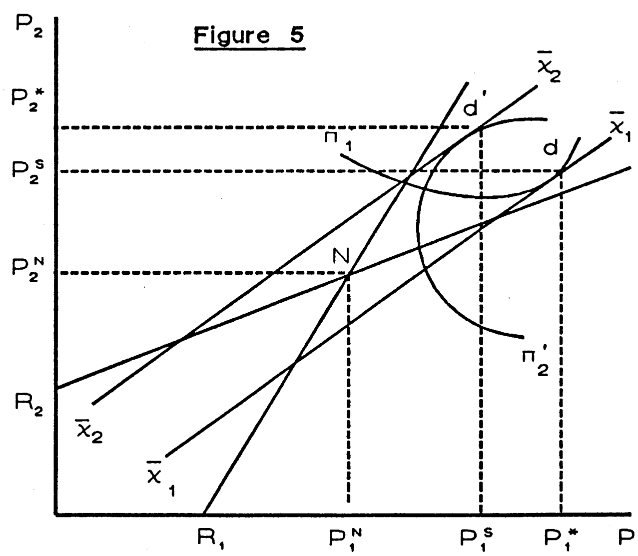
(ii) *Increases the prices of the processed products*

(iii) *The profits of both firms increase*

Proof.

This result is illustrated in **Figure 5** where $\overline{x}_1\overline{x}_1$ is the quota constraint on firm 1 and $\overline{x}_2\overline{x}_2$ is the corresponding constraint for firm 2. It is assumed that these restrictions are symmetric. Above $\overline{x}_1\overline{x}_1$ and below $\overline{x}_2\overline{x}_2$, the quotas are binding on firms 1 and 2 respectively.

A Nash equilibrium in prices is sought in this game. Given *Proposition 2*, firm 1 does not set a price below p_1^* as firm 2 will always set p_2^s in order to make the quota bind. Similarly for firm 2, it knows that setting a price below p_2^* will result in firm 1 setting p_1^s in order for the quota to bind on firm 2. Consequently, neither firm sets a price below the set (p_1^*, p_2^*). Therefore, each firm chooses a price to maximize profits where its quota will just bind given the other firm is bound by its quota constraint, i.e. (p_1^*, p_2^*), which implies a pure strategy equilibrium at points **d,d′** [5], with the associated profit levels π_1' and π_2'. Hence the welfare effects of quotas on both food processors are unambiguous, the prices and profits of both firms increase and output of both firms falls. The consumer faces higher prices for processed food products.



In concluding this discussion, *Propositions 3* and *4* can be synthesized by recognizing that output quotas have the same effect as capacity constraints in a two-stage game, where in the first period, capacities are chosen and in the second, prices are set to satisfy these capacities. Kreps and Scheinkman have shown that when firms are capacity constrained in a price game, the prices they set are those that would be generated by the Walrasian auctioneer in a one-stage quantity game. This result is driven by the assumption of the efficient rationing rule, which is the same as that employed in the analysis above.

[5] This is a stable equilibrium because in a symmetric game, there is no price wedge over which consumers can arbitrage, i.e. there is no need for rationing.

Consequently, *Proposition 4* can be seen as generating Cournot-equivalent prices for the processed food products, i.e. the equilibrium with quotas is the same for both quantity and price strategies[6].

3. Summary

The aim of this paper has been to consider how sensitive the outcomes of agricultural and food policy are to the underlying game being played by food processors. Using the example of output restrictions in a duopoly market structure, it has been shown that when a restriction is placed on only one firm, both benefit when they compete in price, while the other firm benefits when competition is in quantities. When restrictions are imposed on both firms, they benefit under both price and quantity competition, the effect being exactly similar under efficient rationing. Consumers clearly lose under all of these policy experiments and in three cases it would seem that food processing firms have an incentive to encourage government to maintain the restrictions. By assumption, farmers in all cases receive the same per unit price for the raw commodity at a lower level of output.

It might be argued that these results have been restricted to Cournot and Bertrand behavior. However, they are the logical Nash equilibria in one-shot, simultaneous move games, nonetheless, other oligopoly equilibria such as Stackelberg leadership could be examined. Different forms of behavior, other types of policy and empirical assessment can be considered as part of future research in this area.

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[6] It should be noted that Davidson and Deneckere (1986) have shown that for other rationing rules, the Cournot outcome does not necessarily emerge.

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